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Results are presented of the effects of K, KO_2, KOH and methyl bromide vapors on the combustion of diluted H_2-CO/O_2-N_2 mixtures. A flat diffusion flame produced by an opposed-jet burner was scanned incrementally in the infrared wavelengths to study the combustion inhibition reactions of the mentioned additives. K inhibited the reaction of hydrogen over a range of additive concentration from 0.3 to 1320 molar ppm for lean to rich flames for stoichiometric ratios of 0.95 to 1.15. The other two potassium additives inhibited or enhanced the reaction depending on the flame mixture ratio, and for the KO_2 the concentration of the additive. For lean mixtures studied, methyl bromide inhibited the combustion of H_2/CO and CH_4 mixtures.

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THE SUPPRESSION OF AFTERBURNING IN SOLID ROCKET PLUMES BY POTASSIUM SALTS

Prepared by: Eugene Miller

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Contract: Grant AFOSR-83-0358

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ABSTRACT

The exhaust plume of a minimum-smoke solid rocket contains significant concentrations of hydrogen and carbon monoxide which when mixed with ambient air react to water and carbon dioxide producing visible flash and increased infrared radiation. Both reactions produce undesirable signatures and interference with optical guidance systems. Potassium salts have been added to propellant charges to inhibit afterburning in both guns and rockets. They have not always been effective, the inhibiting effect of the salt being related to gas composition and temperature in a complex manner which is not completely understood. Further, there is disagreement as to whether it is KOH, KO_2, or K that is most important in the afterburning suppression. Results are presented here of two years of an investigation sponsored by AFOSR on the efficacy of each of these on the combustion of diluted H_2-CO/O_2-N_2 mixtures. Initial research included studies of the effects of methyl bromide on these mixtures and on CH_4-N_2/O_2-N_2 mixtures. A flat diffusion flame produced by an opposed-jet burner, simulating the reaction conditions in the boundary layer of the plume, was scanned incrementally in the infrared wavelengths to follow the inhibition reactions.

It was found that K vapors inhibited the reaction of hydrogen over a range of additive concentration from 0.3 to 1320 molar ppm for lean to rich flames for stoichiometric ratios of 0.95 to 1.15. The other two additives inhibited or enhanced the reaction depending on the flame mixture ratio and for the KO_2 the concentration of the additive. For lean mixtures studied, methyl bromide was found to inhibit the combustion of hydrogen/CO and CH_4 mixtures.

RESEARCH OBJECTIVES

The Services have increasingly emphasized the development and use of low signature tactical solid rocket motors in recent years. Visible primary and secondary smoke have been largely eliminated from rocket plumes by the removal of ammonium perchlorate oxidizer and most of the other energy and ballistic modifier additives from the propellant formulation - the so-called "minimum smoke" (min-smoke) propellants. The exhaust gases from min-smoke propellants however contain significant concentrations of hydrogen and carbon monoxide which when mixed with ambient air in the plume react to water and carbon dioxide producing visible flash and increased infrared radiation. Also, some of the apparent secondary smoke advantage of min-smoke propellants over reduced smoke propellants (ammonium perchlorate oxidizer with low solids content) is lost since the hydrogen in the plume reacts to form additional water which is available for potential condensation to smoke. The research supported was directed toward preventing or at least inhibiting the signatures due to afterburning.

It is known that potassium salts inhibit the reactions of hydrogen and carbon monoxide to water and carbon dioxide respectively.[1,2] Potassium salts such as KNO_3 and K_2SO_4 have been added to propellant charges at a level of 1 - 3 wt pct to suppress gun muzzle flash [3] and rocket plume infrared signature [4]. The mechanism by which the potassium salts inhibit afterburning is controversial, but it probably involves K, KOH and possibly KO_2 reacting with H and OH radicals to break the chain reactions controlling the combustion of hydrogen and carbon monoxide.[5,6,7] Experimental evidence suggests that the reactions take place in the vapor phase. Since only small concentrations of the K, KOH and KO_2 are required, the amounts of salt that have been used in guns and rockets may be excessive. Minimizing the amount used is important because the potassium salts increase radar signatures and the propensity for smoke formation. The effects of excess potassium salts on the latter have been demonstrated in studies reported by the US Army Missile Command.[8]

Under the present grant, the effects of K, KOH and KO_2 on the afterburning reactions were evaluated by introducing them individually as a vapor into a flat diffusion flame of N_2-H_2-CO/O_2-N_2, scanning the flame incrementally, and examining its infrared spectral emission. Initially methane was chosen as the fuel based on experimental convenience and because there was previous research reported in the literature on the effects of potassium and potassium salts on combustion of methane. An opposed-jet diffusion burner adapted from one described by Hahn, Wendt and Tyson [9] was used. The burner configuration permitted study of the chemistry of inhibition of afterburning under conditions simulating those in the plume. In addition, the arrangement made the injection of potassium and its salt vapors into the flame relatively convenient. A Beckman IR spectrophotometer was modified for detection of emission spectra. The scanning technique was a modification of one previously developed by the principal investigator [10].

SUMMARY OF RESEARCH RESULTS

(1) Studies were made of the effects of K, KOH and KO_2 vapor addition on the combustion of N_2-diluted hydrogen-oxygen diffusion flames for lean to rich mixtures with stoichiometric ratios ranging from 0.67 to 1.15. The effects were interpreted from emission spectra from incremental scans of the width of a flat flame in the 3800 - 3000 cm^{-1} spectral range for water and OH bands. It was concluded that K vapors inhibit the reaction of hydrogen over a range of additive concentration from 0.3 to 1320 molar ppm for lean to rich flames for stoichiometric ratios of 0.95 to 1.15. The other two additives inhibit or enhance the reaction depending on the flame mixture ratio, and for the KO_2 the concentration of the additive.

(2) It was determined that methyl bromide inhibits the combustion of methane-air mixtures. It was observed that there was an increased formation of HCHO when methyl bromide was added to lean flames, confirming the reaction scheme proposed by Wilson[11] and data from reference 12. Similar effects were noted in the present experimental data obtained with the H_2-CO flames.

PUBLICATIONS

"The Suppression of Afterburning in Solid Rocket Plumes by Potassium Salts," 1 Nov 84, Annual Report to AFOSR, AFOSR Grant 83-0358;

"The Suppression of Afterburning in Solid Rocket Plumes by Potassium Salts." E. Miller and S. Mitson. AIAA-85-1253; AIAA/SAE/ASEE 21st Joint Propulsion Conference, July 8-10, 1985;

"Study of the Suppression of Rocket Plume Afterburning by Chemical Additives." L. G. McMillion and E. Miller, 23rd JANNAF Combustion Meeting, 20-24 October 1986.

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